PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification [6] : H04J 13/02, 13/04, 11/00	A1	(11) International Publication Number: WO 99/45669 (43) International Publication Date: 10 September 1999 (10.09.99)

(21) International Application Number: PCT/US99/03722

(22) International Filing Date: 1 March 1999 (01.03.99)

(30) Priority Data:

60/076,756	4 March 1998 (04.03.98)	US
09/250,845	17 February 1999 (17.02.99)	US

(71) Applicant: STANFORD TELECOMMUNICATIONS, INC. [US/US]; 1221 Crossman Avenue, Sunnyvale, CA 94088-3733 (US).

(72) Inventors: COX, Timothy, F.; 1808 Channing Avenue, Palo Alto, CA 94303 (US). NATALI, Francis, D.; 1840 36th Street, Pt. Townsend, WA 98368 (US). OHLSON, John, E.; 2706 Ramos Court, Mountain View, CA 94040 (US). TALWAR, Shilpa; 1063 Morse Avenue #203, Sunnyvale, CA 94089 (US).

(74) Agent: ZEGEER, Jim; 801 North Pitt Street #108, Alexandria, VA 22314 (US).

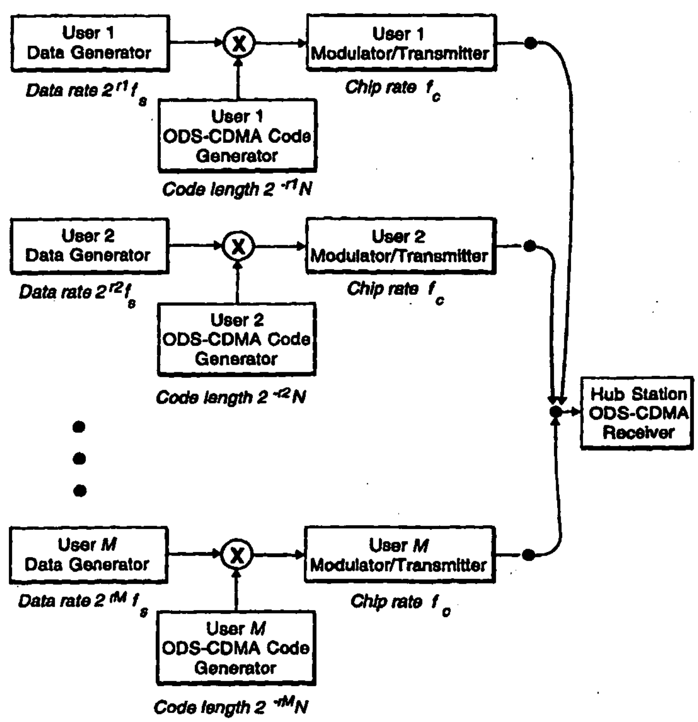
(81) Designated States: AU, BR, CA, CN, JP, KR, MX, NZ, RU, SG, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: APPARATUS FOR INCORPORATING MULTIPLE DATA RATES IN AN ORTHOGONAL DIRECT SEQUENCE CODE DIVISION MULTIPLE ACCESS (ODS-CDMA) COMMUNICATIONS SYSTEM

(57) Abstract

An ODS-CDMA communications system is disclosed with at least one hub station and a plurality of user terminals. Each user is assigned a code which is orthogonal to all of the other user codes. The orthogonal code period is chosen such that the code repeats an integer number of times in a data symbol time and the code is synchronized with the symbol transitions so that no data transitions occur within the code. Thus, the selection of an orthogonal code book which enables a high rate data to be spread using shorter code words, and conversely, low data rate to be spread using longer code words, all or which remain mutually orthogonal.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon			PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

APPARATUS FOR INCORPORATING MULTIPLE DATA RATES IN AN ORTHOGONAL DIRECT SEQUENCE CODE DIVISION MULTIPLE ACCESS (ODS–CDMA) COMMUNICATIONS SYSTEM

Background and Brief Description of Prior Art

Spread spectrum communications is being used for a number of commercial applications and is proliferating at a rapid rate. Synchronous orthogonal direct sequence code division multiple access (ODS-CDMA) has been proposed (see U.S. Patent No. 5,375,140, "**Wireless Direct Sequence Spread Spectrum Digital Cellular Telephone System**", incorporated herein by reference) as an effective technique for improving the capacity, i.e., bandwidth efficiency, of the more conventional quasi-orthogonal CDMA.

In conventional direct sequence (DS) spread spectrum CDMA systems, the individual users transmit on the same frequency using different pseudo-noise (PN) codes. The PN codes are quasi-orthogonal, i.e. they have relatively low but nonzero cross-correlation values with each other.

ODS-CDMA systems are designed such that all signals are received in time and frequency synchronism. Thus all users remain orthogonal to each other and, in an ideal world, any user can be recovered with no multiple access noise from other users. This is most practical in a star configured network where a multiplicity of users transmit to and receive from a single Hub Station. This configuration is used in cellular as well as satellite networks.

In an ODS-CDMA system, each user is assigned a code which is orthogonal to all of the other user codes (i.e. the orthogonal codes have a cross-correlation value of zero with each other). Further, the orthogonal code period is chosen such that the code repeats an integer number of times in a data symbol time (usually once, since this results in the maximum number of available orthogonal

functions). The code epoch is synchronized with the symbol transitions so that no data transitions occur within the code. The number of users is limited by the number of orthogonal codes available, which is equal, at most, to the length of the code. Therefore, the chipping rate is equal to the maximum number of orthogonal users times the symbol rate.

Efficient use of the available bandwidth is accomplished by using bi-phase spreading and MPSK data modulation as taught in U.S. Patent Number 5,687,166, **"Modulation System for Spread Spectrum CDMA Communication,"** incorporated herein by reference.

It is often desirable to accommodate a mix of different rate users where the rates are related by 2^n where n is a positive integer. One code-efficient way to do this is to size the system for the lowest user rate and then demultiplex higher rate data onto multiple orthogonal codes, i.e. data of a user at *4* times the nominal rate would be demultiplexed and spread onto *4* codes which are then summed for transmission. This scheme, while efficient in the use of orthogonal codes, produces a signal with a wide dynamic range which is a disadvantage for the subscriber terminal power amplifier efficiency. It also requires multiple correlators and multiplexing to recover the original data stream. This technique is discussed by Ejzak, et al in "BALI: A Solution for High-Speed CDMA Data," in Bell Labs Technical Journal, vol. 2, no. 3, Summer 1997.

Another technique is disclosed in U.S. Patent Application Serial No. 08/352,313, now U.S. Patent No. 5,574,721, entitled "Orthogonal Code Division Multiple Access Communication System Having Multicarrier Modulation" incorporated herein by reference. In this disclosure, it is suggested that multiple ODS-CDMA signals be transmitted on orthogonally spaced carriers (i.e. spaced at the chipping rate) and the data from a single high rate user is demultiplexed onto the multiple carriers. Once again, this results in a signal with wide amplitude variation.

In U.S. Patent Number 5,416,797 "System and Method for Generating Signal Waveforms in a CDMA Cellular Telephone System," incorporated herein by reference, lower data rates than the nominal are supported on the cell-to-mobile link (which is orthogonal), by repeating data symbols of a low rate user a number of times to obtain the nominal symbol rate. This sequence of symbols is then spread by an orthogonal code and transmitted at a lower power proportional to the lower rate. This technique has the disadvantage of not being orthogonal code space efficient, i.e. each low rate user uses the same amount of code space as a high rate user.

In "Design Study for a CDMA-Based Third Generation Mobile Radio System," IEEE Journal on Selected Areas in Communication, vol. 12, no. 4, May 1994, Baier, et al, propose to use variable length spreading codes to support variable data rates in a CDMA system. However, they propose to use PN codes that are not necessarily orthogonal.

Objects of the Invention

An object of this invention is to provide a means by which an ODS-CDMA communications system can function efficiently with data rates that are not all equal. This non-homogeneity in data rates allows different users to communicate with different data bandwidths while the ODS-CDMA communications system signaling rate and orthogonal nature remain the same as in a homogeneous data rate system.

A further object of this invention is to provide an ODS-CDMA system which supports a mix of users, with data rates related by 2^n, which makes efficient use of the available orthogonal code space, i.e. a user with symbol rate R/k uses 1/k of the code space of a user with symbol rate R.

It is a further object of this invention to ensure that users of all rates transmit a relatively constant amplitude signal. This is of particular importance to the

subscriber terminal where high transmitter power efficiency (at or near saturation) is desirable due to the impact on cost and power consumption.

It is a further object of this invention to keep signal processing complexity to a minimum.

Summary of the Invention

In an ODS-CDMA system, each user is assigned a code which is orthogonal to all of the other user codes (i.e. the orthogonal codes have a cross-correlation value of zero with each other). Further, the orthogonal code period is chosen such that the code repeats an integer number of times in a data symbol time (usually once, since this results in the maximum number of available orthogonal functions) and the code epoch is synchronized with the symbol transitions so that no data transitions occur within the code. Thus, in a perfectly synchronized system, the individual users can be demodulated with no interference from other users.

The number of users is limited by the number of orthogonal codes available, which is equal, at most, to the length of the code. Note that the chipping rate is equal to the maximum number of orthogonal users times the symbol rate. This implies that, for a fixed chipping rate, a system transmitting data at a rate of *R/4* should be able to accommodate *4* times as many users as a system with rate *R*.

Efficient use of code space in a system with a mix of user rates ensures that a user with rate *R/4* will only occupy *1/4* of the orthogonal function space of a user with rate *R*. The invention disclosed herein teaches an efficient way to construct such orthogonal codes by selection of an orthogonal codebook wherein subsequences of the codewords are also orthogonal. With such a codebook, short codes for high rate users are determined directly by the subsequences, and long codes for low rate users are determined by the Kronecker product of the subsequences with an orthogonal codeword allocated to these users. As a

preferred embodiment, the Sylvester construction of a Hadamard matrix is used to generate the orthogonal codebook. Thus, this invention discloses how to efficiently support variable data rates in a synchronous ODS-CDMA communication system with constant chip rate.

The novelty of this invention lies in the selection of an orthogonal codebook which enables high rate data to be spread using shorter codewords, and conversely, low rate data to be spread using longer codewords, all of which remain mutually orthogonal.

Further, using this invention, each user transmits a single code that is constant in amplitude and requires no data multiplexing or demultiplexing. The disclosed technique results in low receiver and transmitter complexity since no additional code generators or correlators are required to accommodate rates that are higher or lower than the nominal data rate. Further, the constant amplitude nature of the signal allows efficient power amplification.

Description of the Drawings

Figure 1. Diagram of multi-rate ODS-CDMA Return Link Structure with *M* users

Figure 2. Diagram of an Exemplary ODS-CDMA Receiver at the Hub Station

Detailed Description of the Invention

A generalized structure for an ODS-CDMA communications system is illustrated in Figure 1. A Return Link structure is shown to facilitate the invention description, however, the concept can be applied to the Forward Link as well. In the Return Link structure, many users communicate with the Hub Station by means of a modulator and transmitter process that uses some medium for transmission. The most common medium for transmission is radio frequency electromagnetic radiation. In this example, all users in the Return Link transmit on the same carrier frequency using the same type of modulator. It is necessary that the users transmit at time instances such that all signals received at the Hub

Station are time synchronous. The waveform transmitted by each user comprises of MPSK modulated data spread with an orthogonal ODS-CDMA code.

In order to accommodate multiple data rates while maintaining a constant chip rate for all users, the length of spreading code for each user is varied. An orthogonal codebook is constructed which enables high rate data to be spread using shorter codewords, and conversely, low rate data to be spread using longer codewords, all of which remain mutually orthogonal. In a preferred embodiment, the Sylvester construction of a Hadamard matrix is used to generate the codebook.

It is well known in the art that a Sylvester-Hadamard matrix of dimension N is defined recursively as

$$H(N) = \begin{bmatrix} H(N/2) & H(N/2) \\ H(N/2) & -H(N/2) \end{bmatrix}$$

where $H(1) = [1]$ and $N = 2^n$, where n is a positive integer. The N rows of the Hadamard matrix $H(N)$ define an orthogonal codebook. For convenience, the rows are indexed from 0 to $N-1$, starting from the top row. It can be seen from the recursive construction of $H(N)$ that it is composed of Sylvester-Hadamard submatrices of the form $\pm H(N/2^k)$, where k is a positive integer ranging from 1 to $n-1$. Since the rows of $H(N/2^k)$ are orthogonal, it follows that the codewords of $H(N)$ consist of subsequences of length $N/2^k$ that are orthogonal as well.

Consider a multi-rate ODS-CDMA communications system with fixed chip rate f_c, some fundamental data symbol rate f_s, and a codebook of N orthogonal sequences such that $f_c = Nf_s$. If there exist M Return Link users with data streams at the fundamental symbol rate, each user may be assigned one of the N orthogonal codewords as long as $M \leq N$. However, if there exist users that request higher or lower data rates compared to the fundamental rate, they may be assigned shorter or longer codewords, respectively. These shorter (longer) codes are constructed from the codeword in a fashion such that the orthogonal

nature of the ODS-CDMA system is maintained and the code space is used efficiently. An illustrative example is considered first to motivate the general approach for constructing these variable length codewords.

Suppose one of the users request a higher symbol rate, say at twice the fundamental rate $2f_s$. Since the chip rate, which is the product of the spreading sequence length and the symbol rate, is fixed, it follows from $f_c = (N/2)(2f_s)$, that the spreading sequence length per symbol must be reduced to $N/2$. This can be implemented by spreading alternate symbols of the high rate user by the first $N/2$ chips of a codeword and the last $N/2$ chips of the same codeword. Since this codeword is sub-divided into two $N/2$ subsequences, the remaining codewords must be orthogonal over each of these two subsequences such that the users at fundamental rate f_s and the high rate user at $2f_s$ do not mutually interfere, thereby maintaining orthogonality in the ODS-CDMA system. Consider allocating the k^{th} codeword to this user ($k = 0, 1, \ldots, N-1$). If a Sylvester-Hadamard matrix is used as the orthogonal codebook, the $(k+(N/2))_{mod(N)}$ codeword does not possess the required $N/2$ subsequence orthogonality since it contains the same two subsequences (up to a ± sign) and therefore cannot be allocated to other users. For example, if the high rate user is assigned the k^{th} code word $c_k = [S_{N/2} \quad S_{N/2}]$, the codeword $c_j = [S_{N/2} \quad -S_{N/2}]$ for $j = (k+(N/2))_{mod(N)}$ cannot be assigned to another user, and vice versa. Note that if a user at rate $2f_s$ is assigned a single short subsequence in $N/2$ space (say subsequence $S_{N/2}$), this is equivalent to using two codewords in the N space codebook. Hence, in an alternative implementation, a rate $2f_s$ user may be supported by assigning the user a shorter subsequence of length $N/2$, and removing the codewords which contain this subsequence from the list of allocable codewords.

In general, a multi-rate ODS-CDMA system with a codebook of N Sylvester-Hadamard sequences ($N = 2^p$ for some integer p), fundamental data symbol rate f_s, and a fixed chip rate $f_c = Nf_s$, can support users with higher data rates than the fundamental rate. The users may request to transmit data at rates $2^r f_s$, where r

ranges from 0 to p. This is achieved by reducing the length of the spreading code to $N/2^r$ such that the chipping rate, $f_c = (N/2^r)(2^r f_b)$, remains constant. Subsequences of length $N/2^r$ can be generated by sub-dividing an allocated codeword of length N into 2^r sub-codes. These sub-codes are used to spread 2^r consecutive symbols of a data stream at rate $2^r f_b$. Note that in the case of the Sylvester-Hadamard sequences, any codeword of length N is a repeated subsequence of length $N/2^r$ (up to a ± sign), which is orthogonal to the other non-identical subsequences of the same length.

Further, if the k^{th} codeword is composed of a repeated subsequence of length $N/2^r$ (up to a ± sign), then the codewords $(k+i(N/2^r))_{mod(N)}$, for all $i = 1,2,...,2^r-1$ and $r > 0$, are also composed of the same subsequence (up to a ± sign), and are no longer available for allocation, if system orthogonality is to be preserved. Indeed, supporting 1 user at data rate $2^r f_b$ is effectively equivalent to supporting 2^r users at rate f_b since 2^r-1 codes are rendered unusable.

In a network setting where multiple users are transmitting at different data rates, appropriate provisions must be made for accommodating the data rate request of a new user in terms of checking for allocable subsequences. In fact, the network controller must, before assigning a subsequence, make certain that it is not contained in the longer subsequence of a lower rate user (since the lower rate user would not be orthogonal over the subsequence length). Further, it must not contain a subsequence of shorter length that is already in use.

It is advantageous for the network controller to have the capability to change orthogonal sequence assignments periodically in order to most efficiently use the code space as the mix of user rates changes. In addition, since the symbol interval of data at rate $2^r f_b$ is reduced to $1/2^r$ times the symbol interval of data at rate f_b, it may be desired, depending on the application, to increase the transmit power by 2^r to maintain the same level of performance.

Conversely, a multi-rate ODS-CDMA communication system with a codebook of N orthogonal sequences, fundamental data rate f_s, and a fixed chip rate $f_c = Nf_s$, can support users with lower data rates than the fundamental rate. The users may request to transmit data at rates $f_s/2^r$, where r is a positive integer ranging from 0 to q. A lower rate user, at rate $f_s/2^r$, is assigned a longer spreading code of length 2^rN such that the chipping rate, $f_c = (2^rN)(f_s/2^r)$, remains constant. The long code is constructed from the codeword allocated to this user, c_k, $k = 0,\ldots,N-1$, as follows.

First, an orthogonal function set $G(2^r)$ of size 2^r is constructed. This could be, but is not necessarily, a Sylvester-Hadamard matrix. The Kronecker product of the j^{th} row of $G(2^r)$ with the codeword c_k produces a member L_{jk}, $j = 0,\ldots,2^r-1$ of a set of 2^r mutually orthogonal codes of length 2^rN. Each of these long sequences is orthogonal to codewords c_l, where $l \neq k$, as well as longer code words L_{jl} formed by the Kronecker product of each row of $G(2^r)$ with the codewords c_l. Thus, up to 2^r users of rate $f_s/2^r$ can be assigned to a single code word c_k by assigning each user a different row of $G(2^r)$. This code construction technique can be generalized to accommodate a mix of users with different rates of the form $f_s/2^r$, with the maximum aggregate symbol rate bounded by f_s.

The proposed scheme suggests that the symbol interval of data at rate $f_s/2^r$ is increased to 2^r times the symbol interval of data at rate f_s. It may be desired that a user at the lower data rate reduce transmit power by 2^r in order to maintain the same symbol-to-noise-energy ratio (Es/No).

The Hub Station receives a superposition of signal waveforms transmitted by the Return Link users. The received signal is demodulated and despread by the multi-rate ODS-CDMA receiver. The despreading operation involves correlating the received waveform with the spreading sequence of the desired user over a symbol interval. Hence, in a multi-rate system that supports users at higher data rates than f_s, the waveform of a user at rate 2^rf_s is despread by correlating it

against the user's allocated $N/2^{r}$ chip subsequence. Conversely, in a multi-rate system that supports users at lower data rates than f_s, the waveform of a user at rate $f_s/2^{r}$ is despread by correlating it with the user's allocated $2^{r}N$ chip Kronecker-product code. In both cases, the despreading operation requires that the codewords of all users be time aligned at the code boundaries in order to preserve orthogonality, and that the data symbol rates of all users be known at the receiver. Furthermore, in a system supporting lower rates, the row index of $G(2^{r})$, used in forming the Kronecker-product code, must be known at the receiver. Appropriate provisions are to be made in a multi-rate ODS-CDMA system to satisfy these requirements.

A functional block diagram of the Return Link structure in the proposed multi-rate ODS-CDMA system is shown in Figure 1. In this figure, M users transmit data to the Hub Station at data symbol rates $2^{r_1}f_s$, $2^{r_2}f_s$,..., $2^{r_M}f_s$, where r_j, $j = 1,\ldots,M$, ranges from 0 to p for a system supporting higher rates than f_s, from $-q$ to 0 for a system supporting lower rates than f_s, and $-q$ to p for a system supporting both high rate and low rates. If the jth user requests a higher rate ($r_j \geq 0$), the user's code generator generates a codeword of length N at rate f_s, which is equivalent to generating 2^{r_j} sub-codes of length $2^{-r_j}N$ in time-division multiplex at rate $2^{r_j}f_s$. On the other hand, if the jth user requests a lower rate ($r_j \leq 0$), the user's code generator generates a Kronecker-product code of length $2^{-r_j}N$ at rate $2^{r_j}f_s$. Hence, at each symbol interval, $T_j = 1/(2^{r_j}f_s)$, the data symbol of the jth user is multiplied by the codeword from the code generator, and the resulting chip sequence is modulated and transmitted to the Hub station.

The Hub Station receives the composite signal waveform of the M Return Link users. The functional block diagram of an exemplary multi-rate ODS-CDMA receiver at the Hub Station is shown in Figure 2. The receiver demodulates the received waveform and despreads it. For the jth user with $r_j \geq 0$, despreading involves formatting each block of N chips of demodulated data into subsequences of length $2^{-r_j}N$, and correlating each of these subsequences with

the sub-code from the code generator. If $\eta \leq 0$, each block of $2^{\eta}N$ chips is correlated with the long code from the code generator. In the absence of channel distortions, the correlator output yields the user data.

A simple illustrative example which embodies the present invention is as follows.

Consider a multi-rate ODS-CDMA system with a codebook derived from Sylvester-Hadamard matrix of dimension $N = 4$,

$$H(4) = \begin{bmatrix} +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 \end{bmatrix} = \begin{bmatrix} c_0 \\ c_1 \\ c_2 \\ c_3 \end{bmatrix}$$

fundamental data symbol rate f_s, and fixed chip rate $f_c = 4f_s$.

Suppose User 1 is assigned codeword 0, $c_0 = [+1 \ \ +1 \ \ +1 \ \ +1]$, and is transmitting at rate f_s. Now, a new user, User 2, requests to transmit at rate $2f_s$. From the codes available for allocation, c_1, c_2 and c_3, only c_1 or c_3 may be allocated to User 2 since the length 2 subsequences of c_2, namely $[+1 \ \ +1]$ and $[-1 \ \ -1]$, are not orthogonal to the corresponding subsequences of c_0. Let code c_1 be assigned to User 2. The chip sequence transmitted by User 1 within the time interval $T_s = 1/f_s$ is $x^{(1)} = s^{(1)}[+1 \ \ +1 \ \ +1 \ \ +1]$, where $s^{(1)}$ is the current data symbol. Similarly, the chip sequence transmitted by User 2 within the same time interval is $x^{(2)} = [s_a^{(2)}[+1 \ \ -1] \quad s_b^{(2)}[+1 \ \ -1]]$, where $s_a^{(2)}$ and $s_b^{(2)}$ are the current data symbols. Note that with the current allocation scenario, only code c_3 is available for allocation to a new user with symbol rate f_s or lower. A user that requests a higher symbol rate cannot be supported unless the codes are reassigned.

The signal received at the Hub Station (after demodulation) is of the form

$$\begin{aligned} r &= x^{(1)} + x^{(2)} \\ &= s^{(1)}[+1 \ \ +1 \ \ +1 \ \ +1] + [s_a^{(2)}[+1 \ \ -1] \quad s_b^{(2)}[+1 \ \ -1]]. \end{aligned}$$

The signal is despread by correlating it with the appropriate spreading code. For User 1, this is achieved by computing the following inner product

$$\hat{s}^{(1)} = \frac{1}{4} r \cdot \begin{bmatrix} +1 \\ +1 \\ +1 \\ +1 \end{bmatrix},$$

which yields the transmitted data symbol. The data symbols of User 2 are retrieved by first partitioning the received chip sequence into 2 subsequences, $r = [r_a \ \ r_b]$, where

$$r_a = s^{(1)}[+1 \ \ +1] + s_a^{(2)}[+1 \ \ -1] \quad \text{and} \quad r_b = s^{(1)}[+1 \ \ +1] + s_b^{(2)}[+1 \ \ -1]$$

and then computing the following inner products

$$\hat{s}_a^{(2)} = \frac{1}{2} r_a \cdot \begin{bmatrix} +1 \\ -1 \end{bmatrix},$$

and

$$\hat{s}_b^{(2)} = \frac{1}{2} r_b \cdot \begin{bmatrix} +1 \\ -1 \end{bmatrix}.$$

Now, suppose a third user, User 3, requests to transmit at rate $f_s/2$. Let this user be assigned codeword c_3 and row 0 of $G(2)$, the Sylvester-Hadamard of order 2. The long spreading code for User 3 is given by the Kronecker product of row 0 of $G(2)$ with the codeword c_3:

$$\begin{aligned} L_{03} &= [+1 \ \ +1] \otimes c_3 \\ &= [\, c_3 \ \ c_3 \,], \end{aligned}$$

which is 8 chips long.

An additional user at rate $f_s/2$ may be accomodated with the orthogonal code constructed by taking the Kronecker product of row 1 of $G(2)$ with c_3 to give $L_{13} = [+1 \ \ -1] \otimes c_3 = [\, c_3 \ \ -c_3 \,]$, or 2 additional users can be supported at the rate $f_s/4$ by taking the Kronecker product of the rows of $G(2)$ with L_{13} to construct $L'_{03} = [+1 \ \ +1] \otimes L_{13} = [\, c_3 \ \ -c_3 \ \ \ c_3 \ \ -c_3 \,]$ and $L'_{13} = [+1 \ \ -1\,] \otimes L_{13} = [\, c_3 \ \ -c_3 \ \ -c_3 \ \ \ c_3 \,]$. Note that the codes L'_{03} and L'_{13} are 16 chips long.

At the Hub Station, the data symbols of User 3 are retrieved by correlating the signal received over time period $T_s = 2/f_s$ with the long code L_{03}. It follows from the construction of the codes that the interference from Users 1 and 2 is zero at the correlator output.

In summary, the example system described above can support higher rates than f_s of $2f_s$, $4f_s$, and lower symbol rates of $f_s/2$, $f_s/4$, ... $f_s/2^q$.

If the multi-rate system allows high rates only, at full capacity with total system throughput $4f_s$, the following allocation scenarios can be supported:

a) *4* users transmit at f_s

b) *2* users transmit at f_s, and *1* user transmits at $2f_s$

c) *2* users transmit at $2f_s$

d) *1* user transmits at $4f_s$

Conversely, if the multi-rate system allows low rates only, for *each* codeword c_k, $k = 0,1,2,3$, some of the scenarios that can be supported are:

a) *1* user transmits at f_s

b) *2* users transmit at $f_s/2$

c) *2* users transmit at $f_s/4$, and *1* user transmits at $f_s/2$

d) *4* users transmit at $f_s/4$

e) 2^q users transmit at $f_s/2^q$

Note that a maximum data rate of f_s can be supported per codeword, yielding, as before, a total system throughput of $4f_s$. Finally, if the multi-rate system allows both high and low data rates, a variety of allocation scenarios are possible, and again the total system throughput is bounded by $4f_s$.

Claims

1. In an ODS-CDMA communications system with at least one Hub Station and a plurality of user terminals, a means for generating a codebook of N orthogonal sequences where $N = 2^p$ for some integer p, a fundamental data symbol rate f_s, and a fixed chip rate f_c where $f_c = Nf_s$, the improvement comprising:

   means for supporting users with multiple data rates by assigning them mutually orthogonal codes of different lengths, while maintaining, the same chip rate, and the same peak-to-average ratio at the transmitter as in a homogeneous data rate system.

2. In the system of Claim 1, where users desiring to transmit data at a rate of $2^r f_s$, where r ranges from 0 to p, are assigned orthogonal subsequences of length $N/2^r$ generated by sub-dividing the allocated codeword of length N, from the codebook of N orthogonal sequences, into 2^r subsequences.

3. In the system of Claim 1, the Sylvester construction of a Hadamard matrix is used to generate the orthogonal codebook such that select subsequences of the codewords in the codebook are also orthogonal.

4. The system of Claim 1, wherein users may request lower rates than the fundamental data symbol rate f_s. The data symbols of a low rate user at rate $f_s/2^r$, where r may range from 0 to q, are spread using a longer code of length $2^r N$, which is constructed by the Kronecker product of a length 2^r orthogonal code and the N chip codeword allocated to this user.

5. The system of Claim 1, wherein users may request lower rates than the fundamental data symbol rate f_s. The data symbols of a low rate user at rate $f_s/2^r$, where r may range from 0 to q, are spread using a longer code of length $2^r N$, which is constructed by the Kronecker product of a row of the Sylvester-Hadamard matrix $H(2^r)$ and the N chip codeword allocated to this user.

6. In an ODS-CDMA communications system with at least one Hub station and a plurality of user terminals, one or more satellites or other means for relaying the signals to and from the Hub Station, a means for generating a codebook of N orthogonal sequences where $N = 2^p$ for some integer p, a fundamental

data symbol rate f_s, and a fixed chip rate f_c where $f_c = Nf_s$, the improvement comprising:

means for supporting users with multiple data rates by assigning them mutually orthogonal codes of different lengths, while maintaining, the same chip rate, and the same peak-to-average ratio at the transmitter as in a homogeneous data rate system.

7. In the system of Claim 6, where users desiring to transmit data at a rate of $2^r f_s$, where r ranges from 0 to p, are assigned orthogonal subsequences of length $N/2^r$ generated by sub-dividing the allocated codeword of length N, from the codebook of N orthogonal sequences, into 2^r subsequences.

8. In the system of Claim 6, the Sylvester construction of a Hadamard matrix is used to generate the orthogonal codebook such that select subsequences of the codewords in the codebook are also orthogonal.

9. The system of Claim 6, wherein users may request lower rates than the fundamental data symbol rate f_s. The data symbols of a low rate user at rate $f_s/2^r$, where r may range from 0 to q, are spread using a longer code of length $2^r N$, which is constructed by the Kronecker product of a length 2^r orthogonal code and the N chip codeword allocated to this user.

10. The system of Claim 6, wherein users may request lower rates than the fundamental data symbol rate f_s. The data symbols of a low rate user at rate $f_s/2^r$, where r may range from 0 to q, are spread using a longer code of length $2^r N$, which is constructed by the Kronecker product of a row of the Sylvester-Hadamard matrix $H(2^r)$ and the N chip codeword allocated to this user.

FIGURE 1

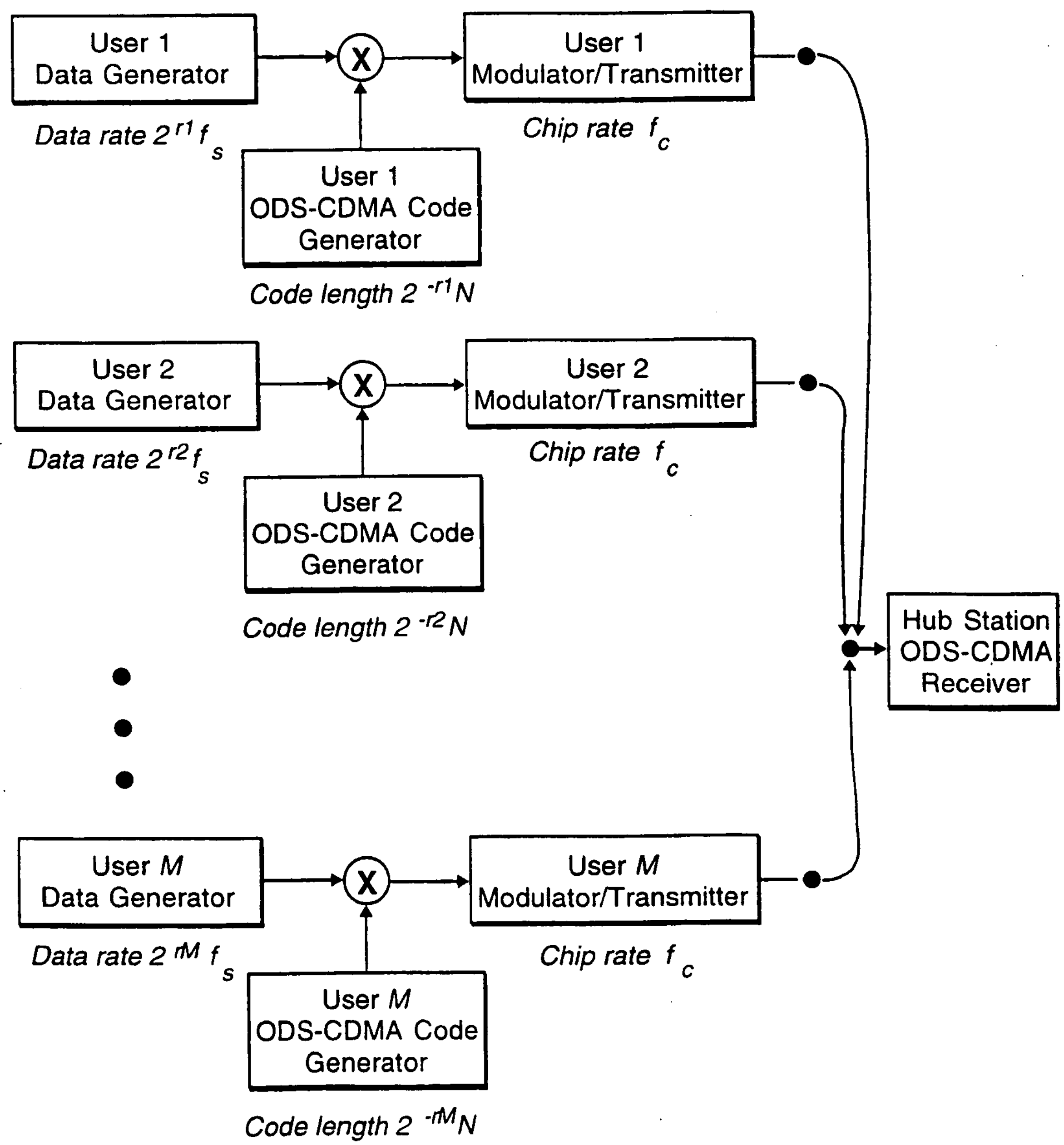
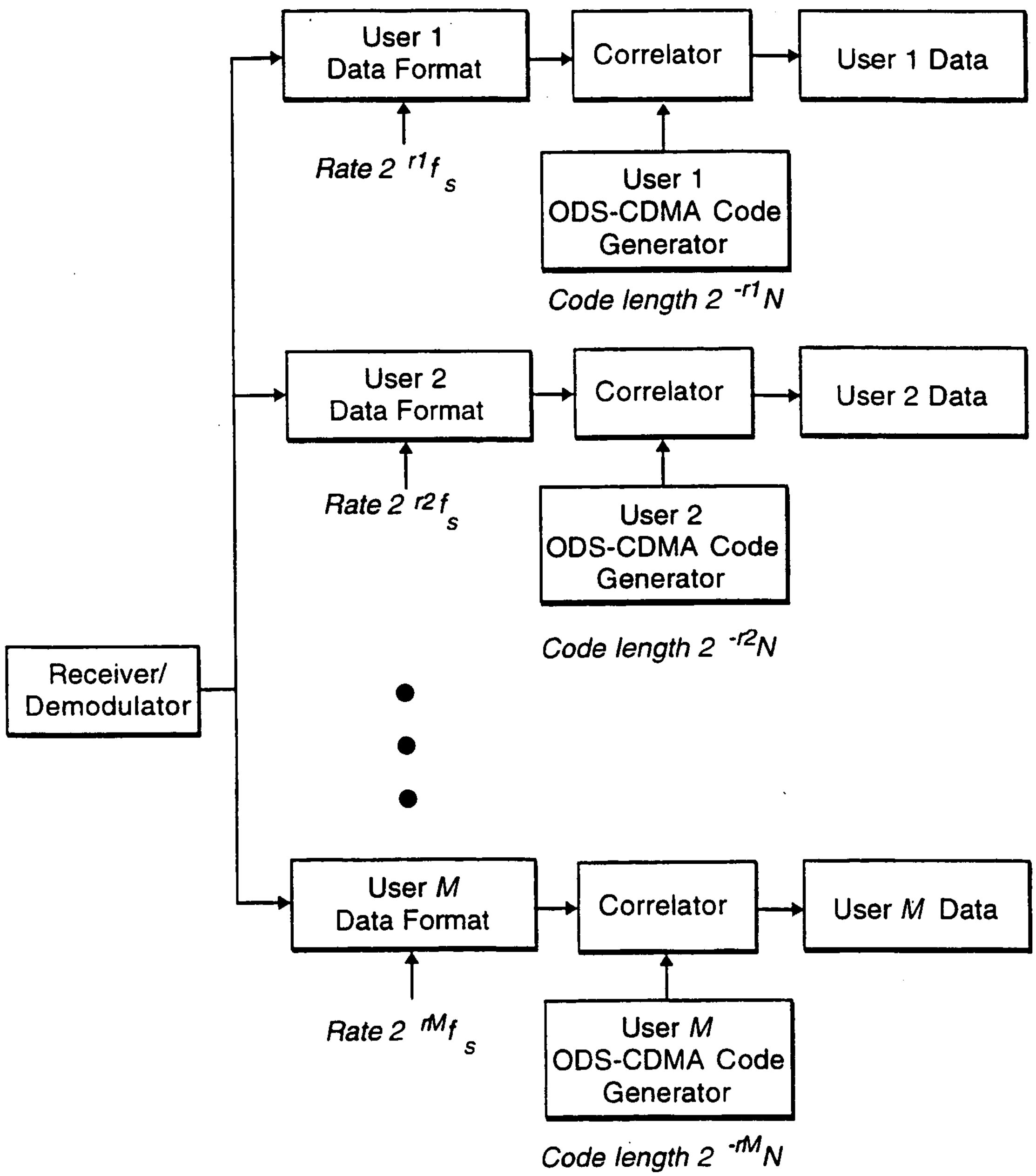

User 1
Data Generator
Data rate $2^{r1} f_s$
User 1
ODS-CDMA Code
Generator
Code length $2^{-r1} N$
User 1
Modulator/Transmitter
Chip rate f_c
User 2
Data Generator
Data rate $2^{r2} f_s$
User 2
ODS-CDMA Code
Generator
Code length $2^{-r2} N$
User 2
Modulator/Transmitter
Chip rate f_c
User M
Data Generator
Data rate $2^{rM} f_s$
User M
ODS-CDMA Code
Generator
Code length $2^{-rM} N$
User M
Modulator/Transmitter
Chip rate f_c
Hub Station
ODS-CDMA
Receiver

FIGURE 2


User 1
Data Format
Correlator
User 1 Data
Rate $2^{r1} f_s$
User 1
ODS-CDMA Code
Generator
Code length $2^{-r1} N$
User 2
Data Format
Correlator
User 2 Data
Rate $2^{r2} f_s$
User 2
ODS-CDMA Code
Generator
Code length $2^{-r2} N$
Receiver/
Demodulator
User M
Data Format
Correlator
User M Data
Rate $2^{rM} f_s$
User M
ODS-CDMA Code
Generator
Code length $2^{-rM} N$

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/03722

A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) : H04J 13/02, 13/04, 11/00
US CL :370/335, 342
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 370/335, 342, 465, 208, 209, 468, 479, 441

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Automated Patent System (U.S. Patents)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,619,524 A (LING et al.) 08 April 1997, see entire document.	1-10
A	US 5,515,396 A (DALEKOTZIN) 07 May 1996, see entire document.	1-10
A	US 5,228,054 A (RUETH et al.) 13 July 1993, see entire document.	1-10
A	US 5,103,459 A (GILHOUSEN et al.) 07 April 1992, see entire document.	1-10

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search
12 MAY 1999

Date of mailing of the international search report
15 JUN 1999

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231
Facsimile No. (703) 305-3230

Authorized officer
MITCHELL SLAVITT Joni Hill
Telephone No. (703) 305-3900